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SELECTED RESULTS FOR METALS FROM LDEF EXPERIMENT A0171

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INTRODUCTION

Metal specimens in disk type and ribbon configurations of interest to various programs at the Marshall Space Flight Center were exposed to the LEO environment for 5.8 years on LDEF Experiment A0171. Most of the metals flown were well heat sunk in the LDEF experiment tray which experienced benign temperatures, but a few metals were thermally isolated allowing them to experience greater thermal extremes. All metal specimens whose preflight weights were known showed a weight change as a result of exposure. Optical property and mass changes are attributed principally to atomic oxygen exposures. Silver and copper were grossly affected whereas tantalum, molybdenum and several preoxidized alloys were the least affected.

Metals contained in this experiment are shown in Table I. Results including mass, surface morphology and optical property changes from selected evaluations of these metals are presented.

RESULTS

Mass Change

Oxidation of metals from thermal atomic oxygen has been shown to be thermally activated, and results from various short term flight exposures of silver to orbital atomic oxygen show a temperature dependence of oxidation. Responses of metals flown on A0171 are consistent with these previous findings. Metals which were well heat sunk to the experiment structure are presumed to have been exposed to a benign thermal environment since the LDEF structure temperature never exceeded 100°F. Several silver ribbon samples were thermally isolated so their upper temperatures were expected to far exceed 100°F. At this time these temperature extremes have not been calculated nor estimated. Most of the exposed metals increased in weight. Preoxidized Ni-Cr-Al and Tophet 30 alloys experienced a slight decrease in weight whereas preoxidized Hos-875 had a slight increase. Reactivity numbers for several metals along with their atomic oxygen accommodation numbers are shown in Table II. The reactivity values were generated based on the assumption that the highest oxide state was formed during exposure. These values may require modification if future work indicates that a different oxide other than the highest state is found. Accommodation numbers shown are defined as the ratio of atomic oxygen atoms reacted to incident atomic oxygen.

Some explanations for the data in Table II can be given in view of the facts that oxidation of metals follows logarithmic and parabolic laws and is highly sensitive to pressure and temperature conditions. Short time exposures at high temperatures should yield high reactivity and accommodation values. The low accommodation and reactivity numbers for several metals from A0171 shown in Table II are consistent with long term exposures under low temperature conditions. The order of magnitude difference in the reactivity between the silver samples attests to the sensitivity of the atomic oxygen reaction to temperature, stress and microstructural differences. The cold rolled silver ribbon contained a stress loop and was thermally isolated from its ambient temperature base so it was expected to thermal cycle through temperatures more extreme than experienced by the disk type samples. The complex dependencies of fluence and temperature prevent the extrapolation of short term effects to long term effects.

Surface Morphology

The disk configured metals were not highly polished so some features which are more distinctive via of the scanning electron microscope (SEM) photographs are somewhat masked by flaws of the machined surfaces. Some differences are noted for the copper exposed and unexposed regions (Figures 1a and 1b). The exposed area shows a fine structure and the unexposed area shows some corrosion which has accumulated on the surface since the samples have returned from flight. The silver oxide formed on the silver samples during exposure produced considerably different surface morphologies for the coarsely machined, fine grained disk samples (Figures 2a and 2b) and the cold rolled ribbon sample (Figure 3). The exposed disk configured silver appears to form peak type oxide scale structures reminiscent of that characteristically observed on exposed polymer structures - a phenomena which has not previously been observed in silver. Elongated silver oxide scales present on the ribbon samples are similar to those formed during short term atomic oxygen exposures on Shuttle flights. Figure 4 is an SEM of molten aluminum sprayed from a debris impact on the mounting hardware onto a copper sample.

Optical Properties

Considerable decreases in solar reflectivity resulted for LDEF exposed silver and copper as shown in Figures 5 and 6, respectively, where their exposed and unexposed regions are compared. More subtle reflectivity changes are present in the lesser reactive materials as noted in Figures 7, 8 and 9. The LDEF exposure of the Ni-Cr-Al alloy resulted in a decrease in reflectance below 2000 nm with this degradation increasing through the visible and ultraviolet spectrum. The reflectance curves for unpolished molybdenum are typical. Its exposure resulted in a slight increase in reflectance above 1700 nm and a more pronounced decrease below 1700 nm. A small decrease in reflectance below 750 nm and a small broadband increase above 750 nm were observed for the tantalum specimen.

SUMMARY

Macroscopic oxidation effects were observed for LDEF exposed silver and copper. Morphology changes induced in exposed silver were peculiar to the type of silver. Quantitative oxidation effects were observed in other metals not previously reported. Atomic oxygen accommodation and reactivity values generated for various metals are characteristic of long exposures at low temperatures.

Additional studies are required to yield explanations for the observed phenomena in these metals. Measurements and calculations related to the metals evaluations on this experiment are only partially complete.

REFERENCES

1. Whitaker, A.F.: RF Oxygen Plasma Effects on Polymeric Materials. A Dissertation Prepared for the Degree of Doctor of Philosophy, March 1989.

2. Whitaker, A.F.; Little, S.A.; Harwell, R.J.; Griner, D.B.; DeHaye, R.F.; and Fromhold, A.T., Jr.: Orbital Atomic Oxygen Effects on Thermal Control and Optical Materials - STS-8 Results. AIAA-85-0416, Jan. 1985.

3. Whitaker, A.F.; Burka, J.A.; Coston, J.E.; Dalins, I.; Little, S.A.; and DeHaye, R.F.: Protective Coatings for Atomic Oxygen Susceptible Spacecraft Materials - STS-41G Results. AIAA-85-7017-CP, Nov. 1985.

TABLE I. METALS ON LDEF EXPERIMENT A0171

METAL	CONFIGURATION	NO. OF SAMPLES
COPPER	1" DIA DISK (1/2 EXP)	(2)
TITANIUM Ti-75A	1" DIA DISK (1/2 EXP)	(1)
MOLYBDENUM	1" DIA DISK (1/2 EXP)	(1)
MAGNESIUM AZ31B	1" DIA DISK (1/2 EXP)	(1)
Ni-14Cr-14al-2Zr ALLOY		
- PREOXIDIZED	1" DIA DISK (1/2 EXP)	(1)
- AS RECEIVED	1" DIA DISK (1/2 EXP)	(1)
SILVER	1" DIA DISK (1/2 EXP)	(2)
NIOBIUM	1" DIA DISK (1/2 EXP)	(1)
TOPHET-30		
- PREOXIDIZED	1" DIA DISK (1/2 EXP)	(1)
- AS RECEIVED	1" DIA DISK (1/2 EXP)	(1)
HOS-875		
- PREOXIDIZED	1" DIA DISK (1/2 EXP)	(1)
- AS RECEIVED	1" DIA DISK (1/2 EXP)	(1)
TUNGSTEN	1" DIA DISK (1/2 EXP)	(1)
ALUMINUM 2219	1" DIA DISK (1/2 EXP)	(1)
TANTALUM	1" DIA DISK (1/2 EXP)	(1)
SILVER FILMS ON VARIOUS SUBSTRATES	1" DIA DISK FULLY EXPOSED	(18)
ALUMINUM FILMS ON VARIOUS SUBSTRATES	1" DIA DISK FULLY EXPOSED	(17)
SILVER-COLD ROLLED RIBBON	1/2" x 1"	(4)
SILVER-COLD ROLLED RIBBON IN STRESS LOOP	1/2" x 2-1/2"	(1)
COPPER IN FLAT CONDUCTOR CABLE	1/4" x 5"	(MULTISTRANDED)
SILVER-ON SOLAR CELLS, INTERCONNECTS AND BACK METALLIZATIONS	----	VARIOUS CONFIGURATIONS AND MULTIPLE SAMPLES
COPPER-WELD INNERCONNECTS	----	PARALLEL GAPS

AND MULTIPLE
SAMPLES

TABLE II. ATOMIC OXYGEN EFFECTS ON SEVERAL METALS FROM EXPERIMENT A0171

METAL	ATOMIC OXYGEN* ACCOMMODATION	ATOMIC OXYGEN REACTIVITY (CM^3/ATOM)
SILVER (MULTI CRYSTALLINE DISK)	$1/10^3$	3.6×10^{-26}
SILVER (COLD ROLLED RIBBON IN STRESS LOOP - THERMALLY ISOLATED)	$8/10^3$	2.8×10^{-25}
COPPER	$2/10^4$	2.0×10^{-26}
MOLYBDENUM	$3/10^4$	1.44×10^{-27}
TITANIUM (75A)	$9/2 \times 10^5$	3.9×10^{-27}

* AO ACCOMMODATION IS THE RATIO OF ATOMIC OXYGEN ATOMS ACCOMMODATED TO INCIDENT ATOMIC OXYGEN ATOMS.

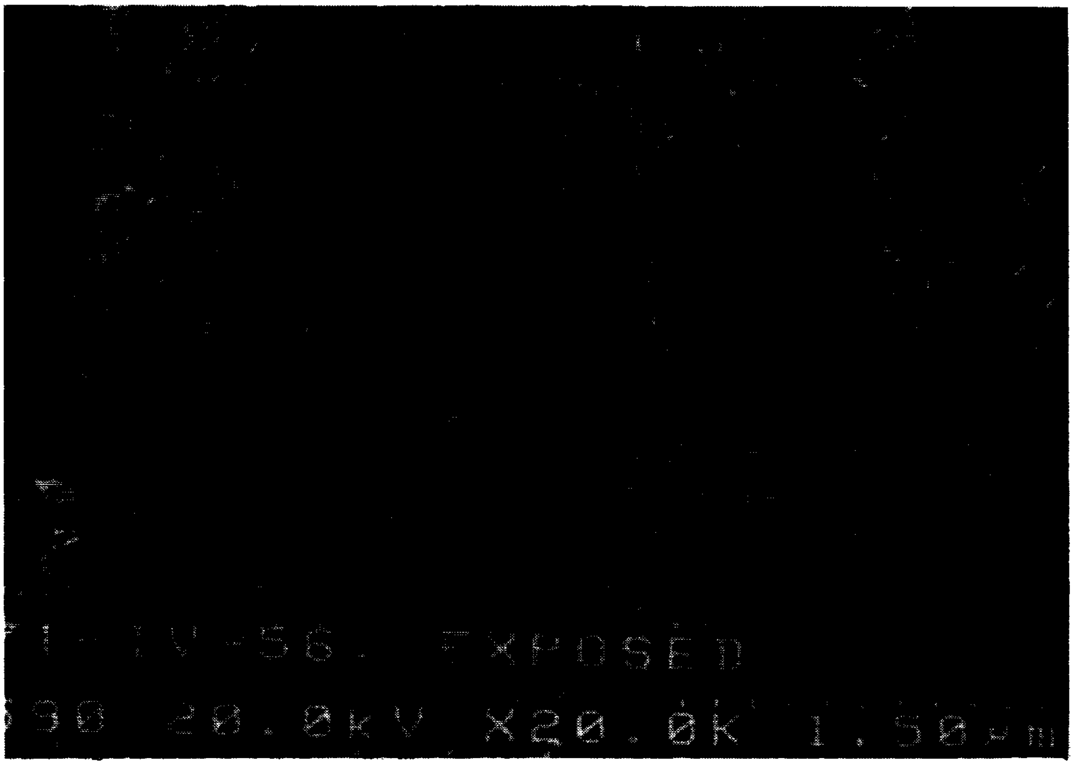

Figure 1a. Exposed Copper Surface Showing Fine Oxide Structures.

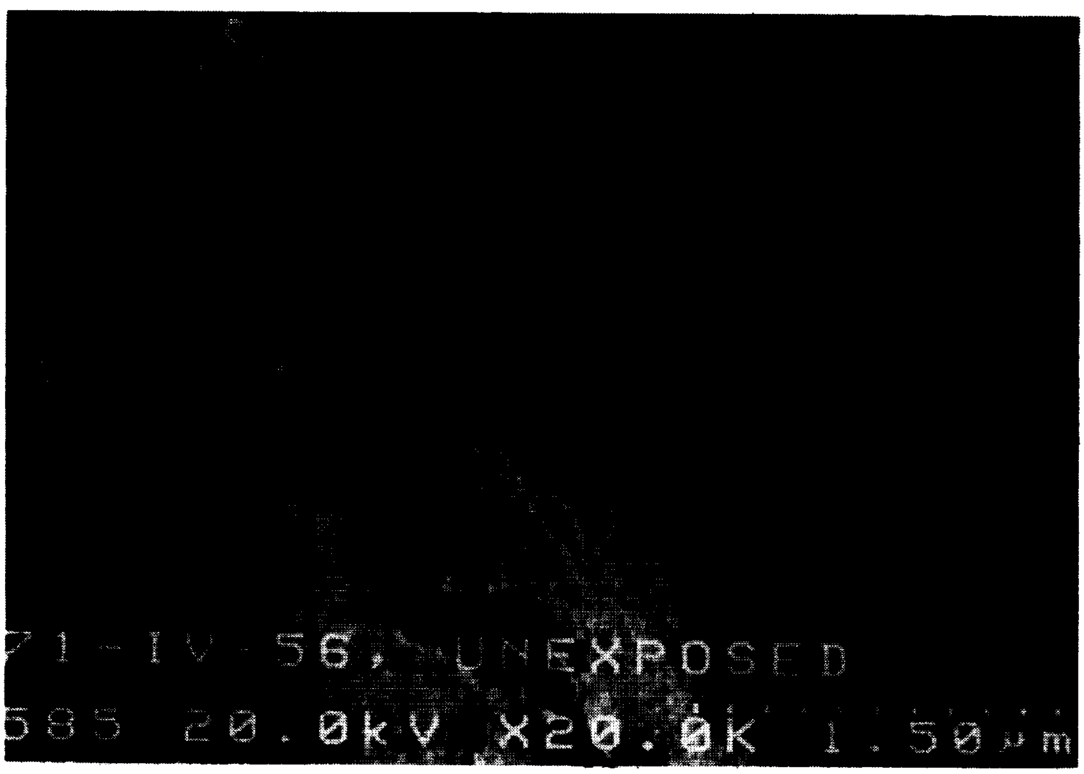

Figure 1b. Unexposed Copper Surface Showing Some Accumulated Corrosion.

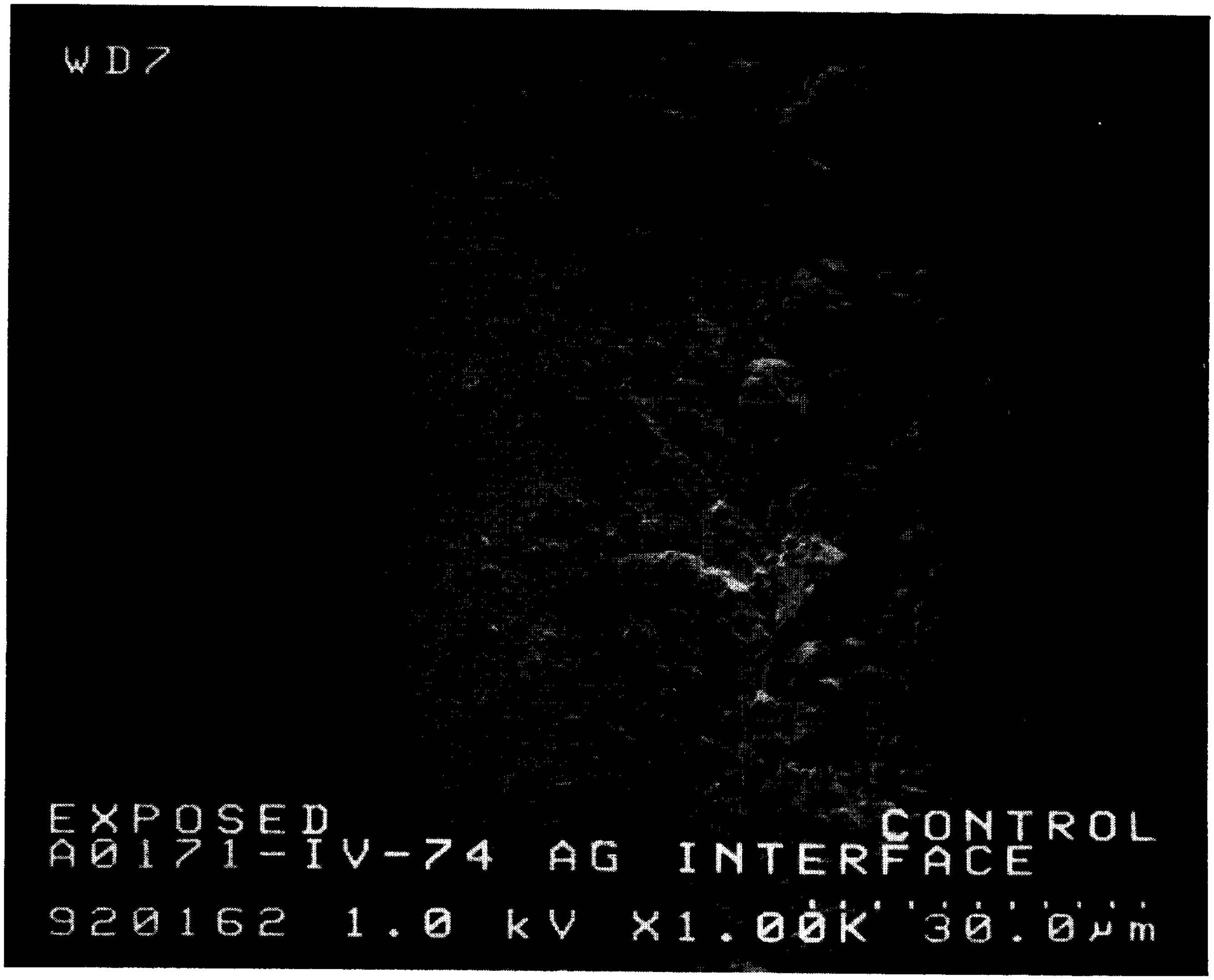

Figure 2a. Scanning Electron Microscope (SEM) View of Silver Exposed (Left), Interface (Center), and Unexposed (Right) Surfaces of Coarsely Machined, Fine Grain Disk Sample.

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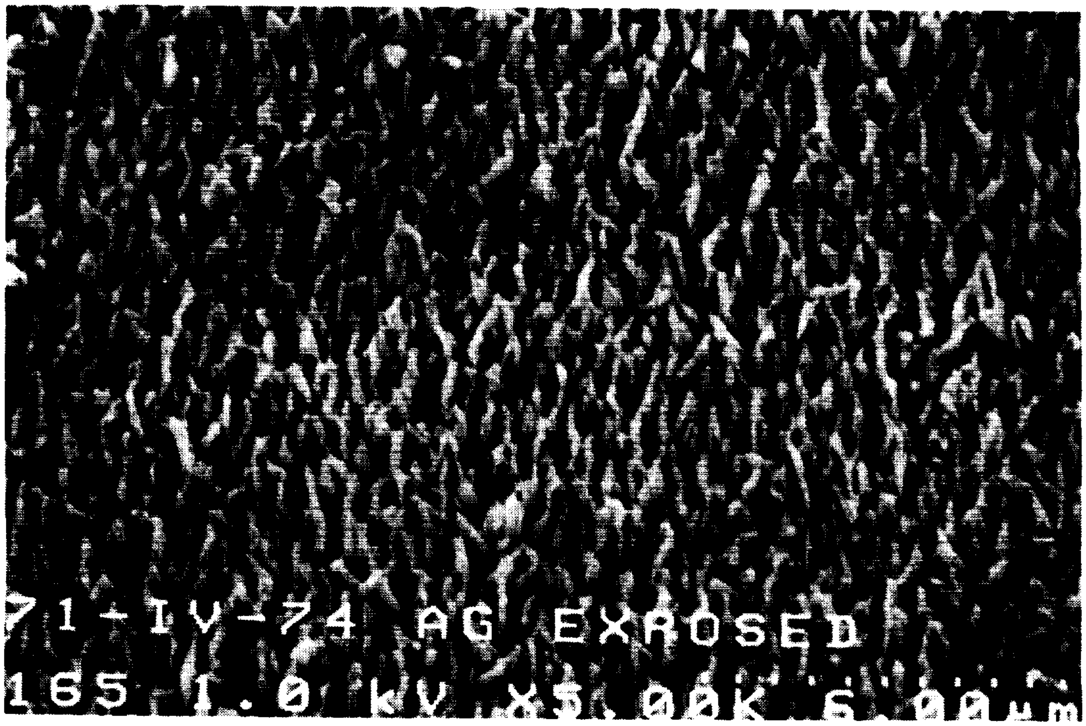

Figure 2b. Exposed Area of Silver from SEM Photograph of Disk Sample.

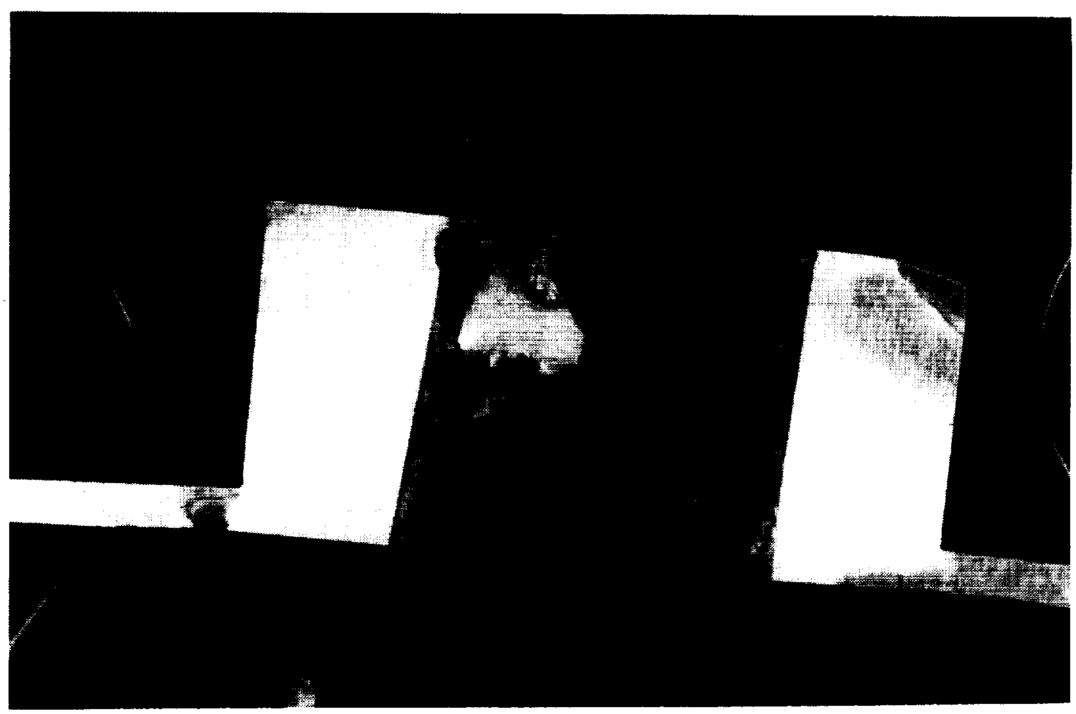

Figure 3. Cold Rolled Silver Ribbon Showing Exposed Area (Dark Scale) and Protected Area.

Figure 4. Scanning Electron Microscope View of Sample Coated With Aluminum Produced From Debris Impact.

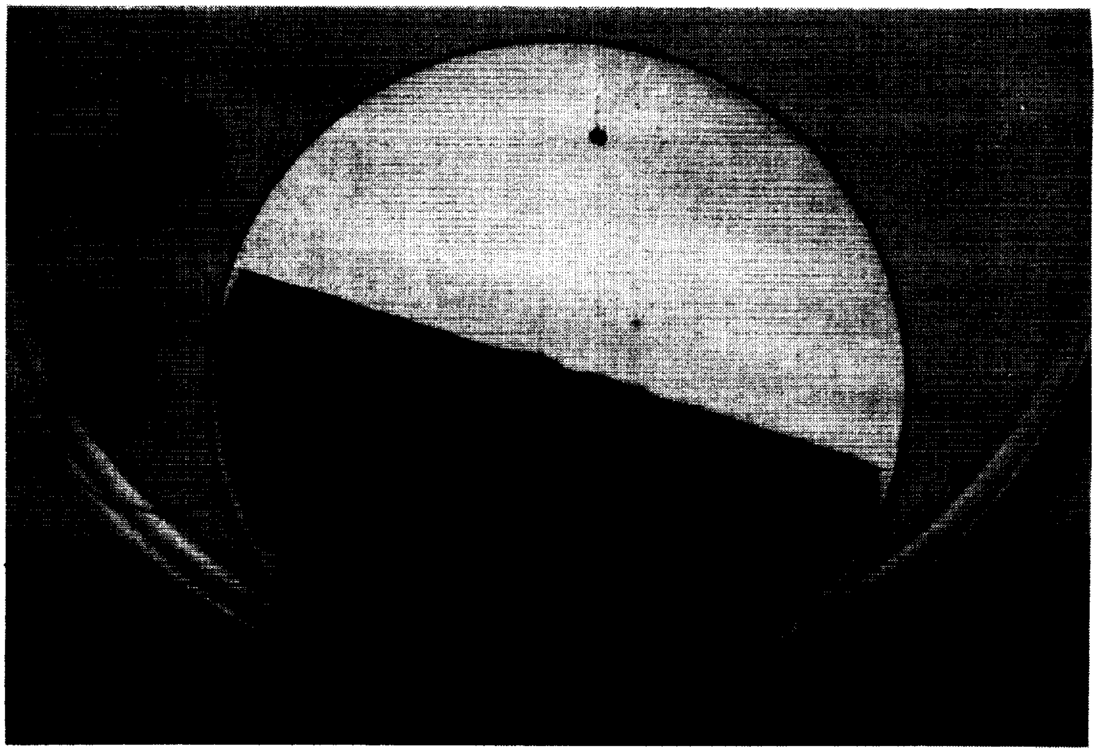

Figure 5. Dark Region of Silver Disk Indicates Area of Decreased Reflectivity.

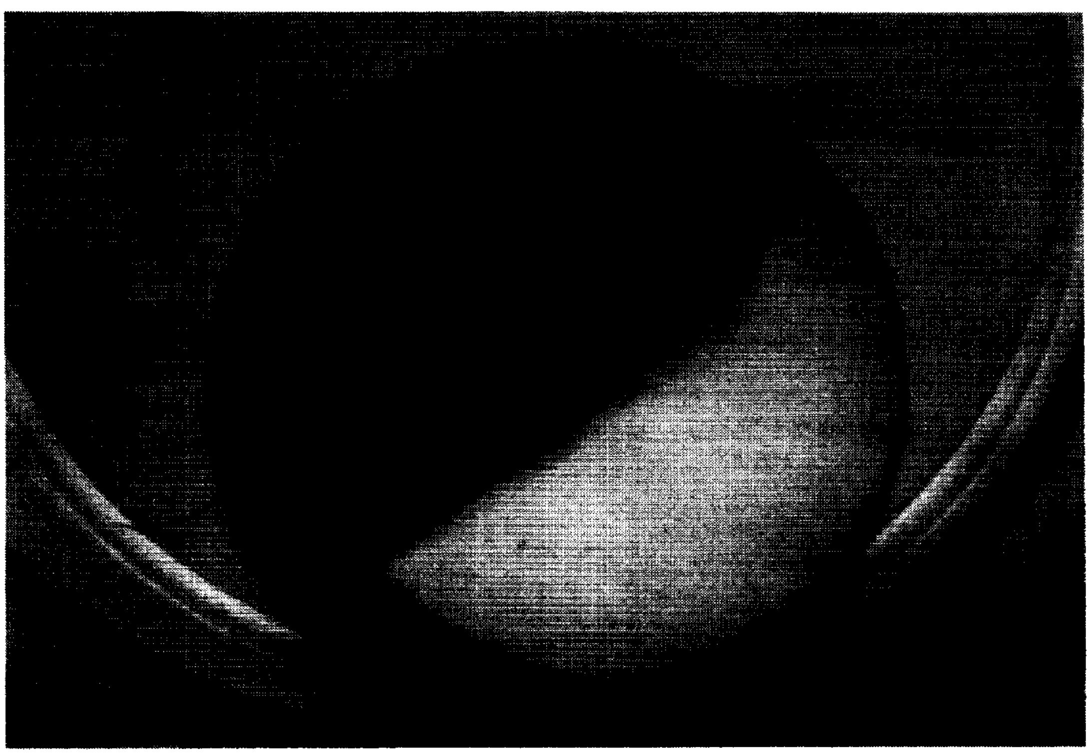

Figure 6. Dark Region of Copper Indicates Area of Decreased Reflectivity.

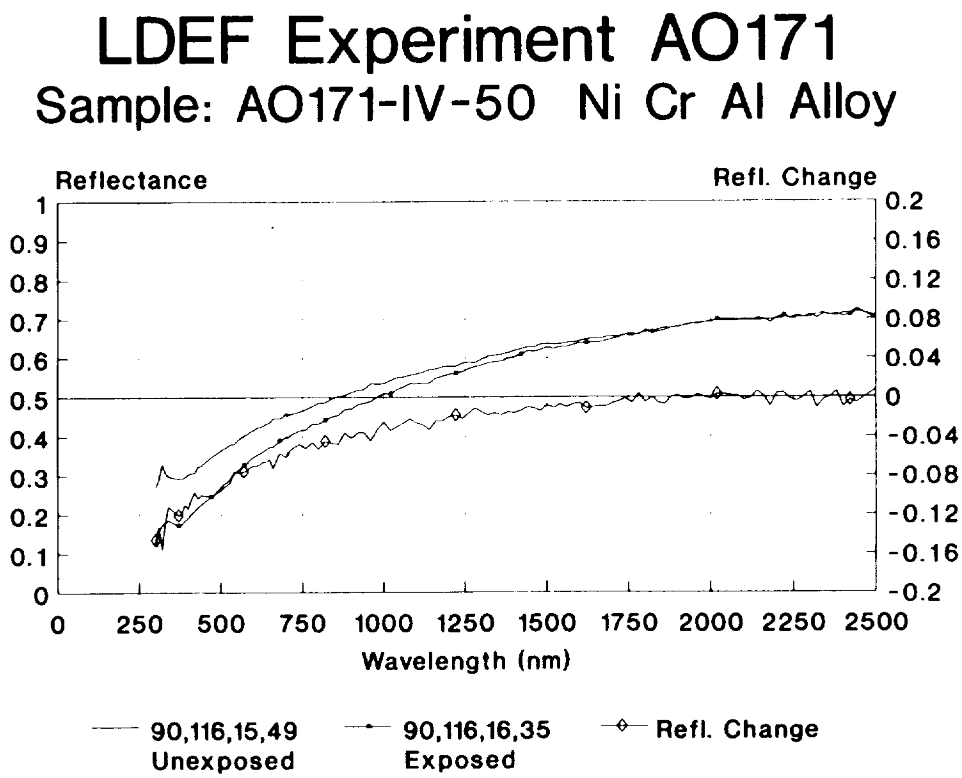

Figure 7. Solar Reflectivity Data for Ni-Cr-Al Alloy.

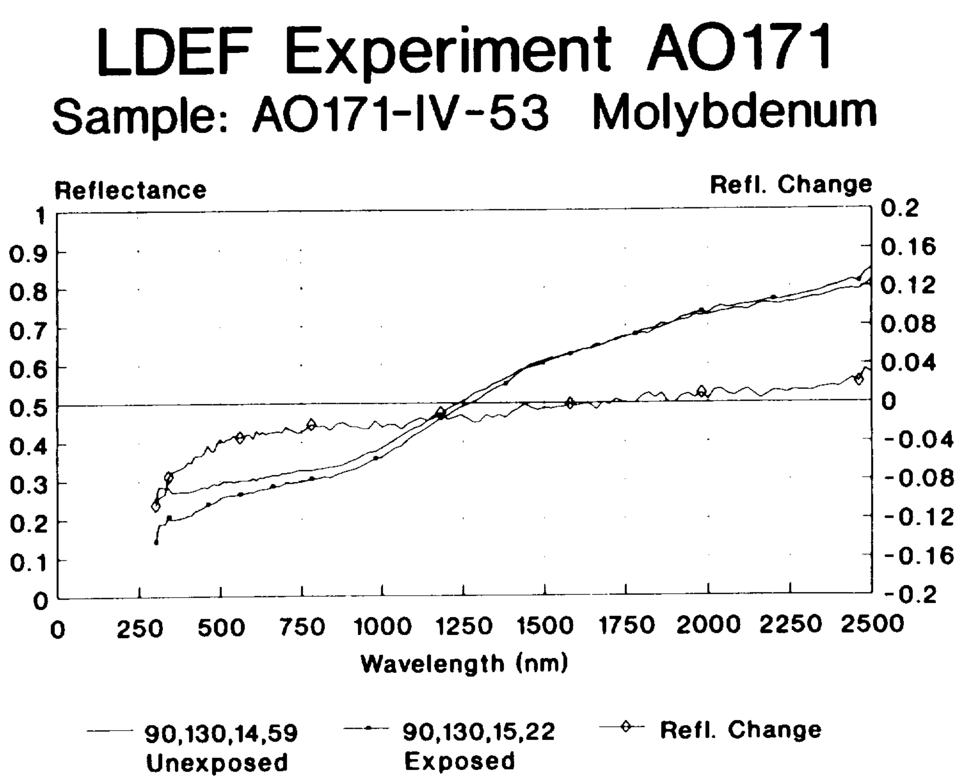

Figure 8. Solar Reflectivity Data for Molybdenum.

LDEF Experiment AO171
Sample: AO171-IV-73 Tantalum

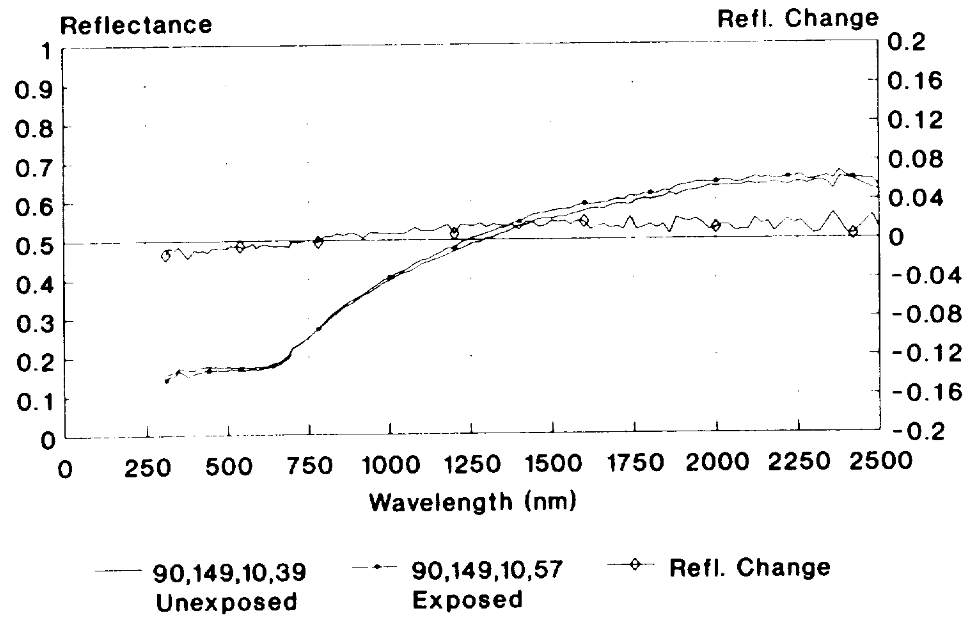

Figure 9. Solar Reflectivity Data for Tantalum.